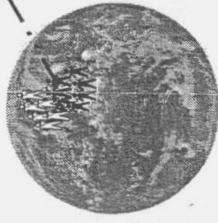


# Multi-Target Single Cycle Instrument Placement

*Sojourner*

- Max distance from Lander: 12 M
- Total distance traversed 100M
- Time spent waiting: 40-75%
- 2.4 uplinks per science target
- Science cut in half during extended mission



*MER*

- 3-4 sols for instrument placement on a science target
- 10 sols at each interesting rock
- 240 co-located ground support scientists and engineers for 24/7 operations (primary mission)

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# Robotic Site Survey

*JPL Research Center*

Atacama Desert survey showed 0.08% - 0.1% of rocks contain microbial colonies\*

- Inspect 1000's rocks
- Many targets per sol
- Rapid preliminary remote and contact survey
- With follow-up measurements on interesting rocks



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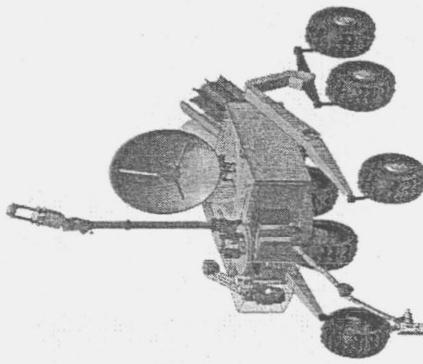
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*NASA*

# Multi-SCIP Research Goals

Multi-Target Single Cycle  
Instrument Placement  
(Multi-SCIP):

- 10m approach
- 1 cm accuracy
- Multiple targets / command cycle
- Safe operations
- Safe instrument placements
- Respect flight rules (e.g., power and time constraints)



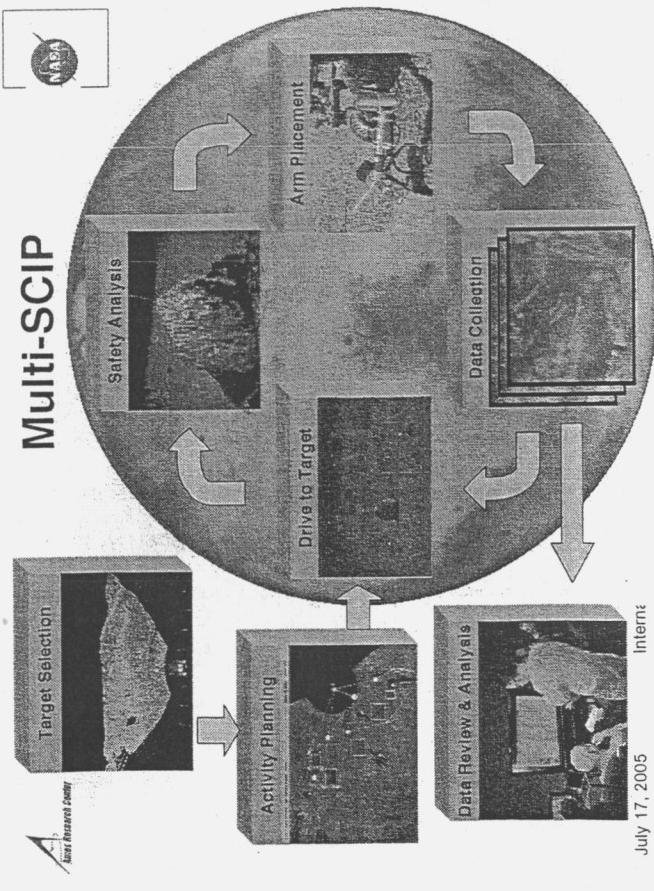
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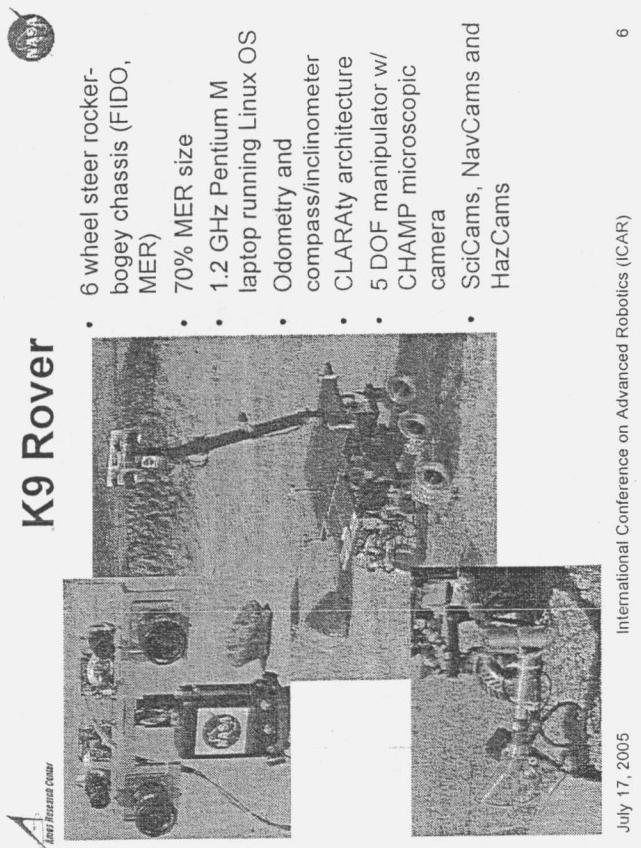
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## Mult-SCIP

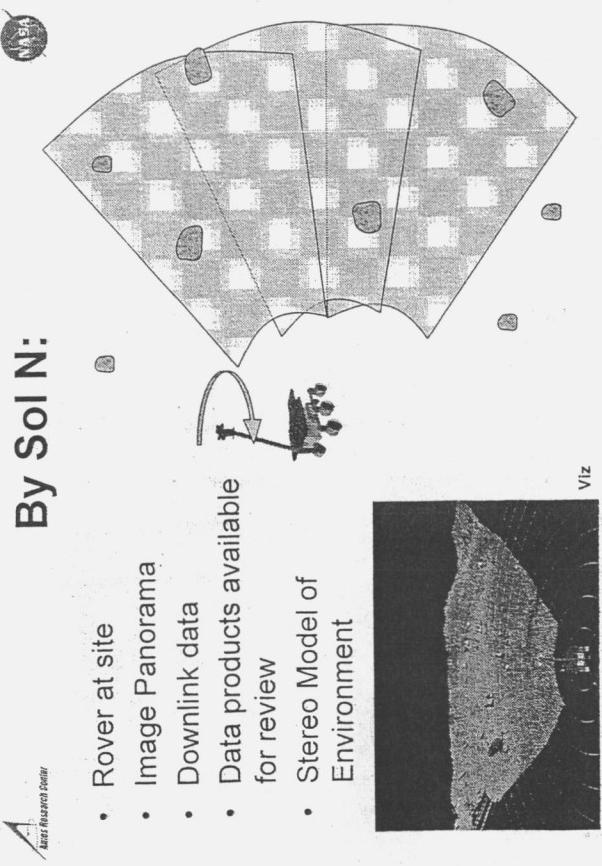


## K9 Rover

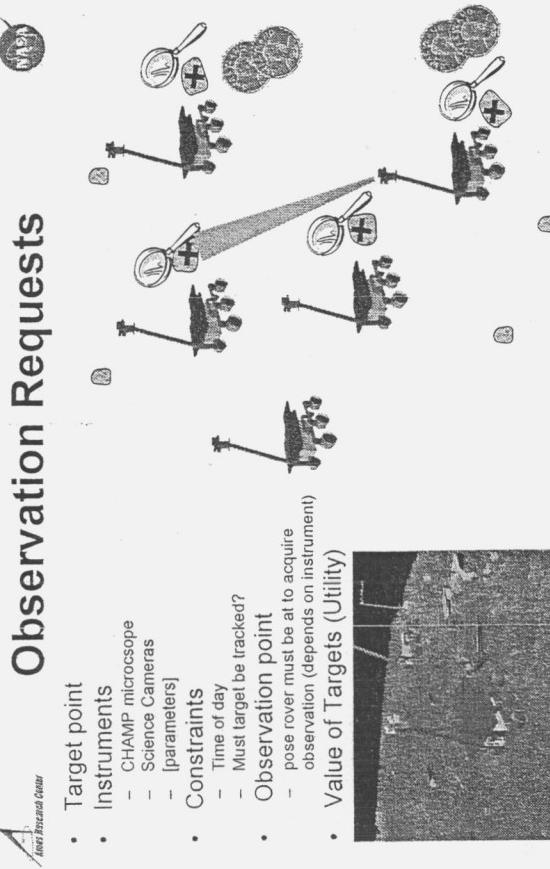


6

## By Sol N:



## Observation Requests



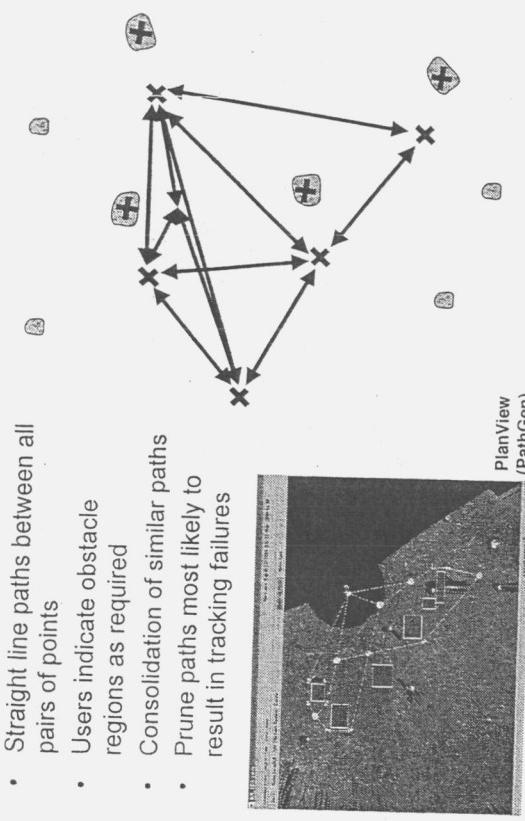
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## NASA Ames Research Center Path Generation

- Straight line paths between all pairs of points
- Users indicate obstacle regions as required
- Consolidation of similar paths
- Prune paths most likely to result in tracking failures



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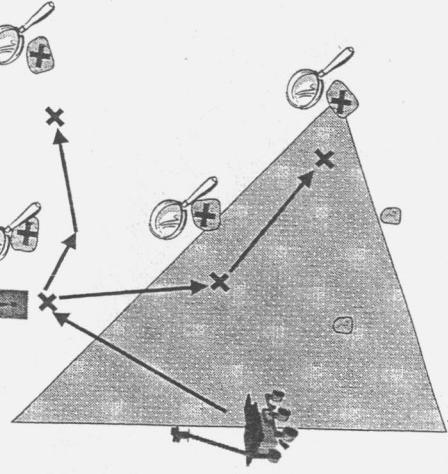
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## NASA Ames Research Center Off-Board Contingency Planning

- Uncertainty everywhere!
- Multiple Targets:

  - Over-subscription problem – more targets than resources
    - Solve “orienteering problem” for goal selection
  - Increased chance of losing targets as tracking “constraints” violated.
  - Contingency plans from points where failure is detected.

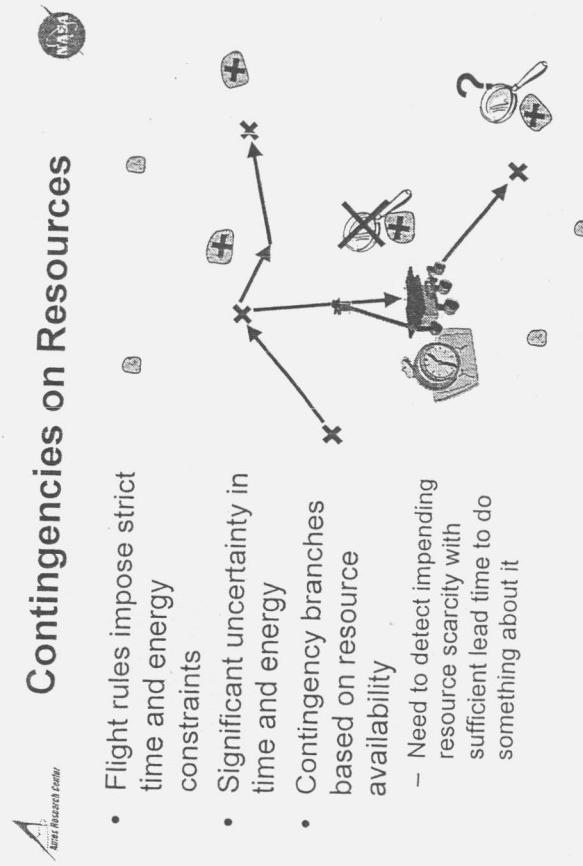


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## NASA Ames Research Center Contingencies on Resources

- Flight rules impose strict time and energy constraints
- Significant uncertainty in time and energy
- Contingency branches based on resource availability
  - Need to detect impending resource scarcity with sufficient lead time to do something about it



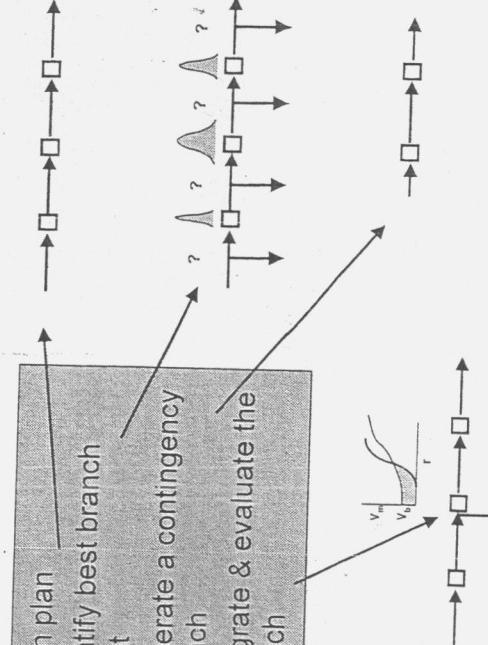
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## NASA Ames Research Center Contingency Planning Approach

1. Main plan
2. Identify best branch point
3. Generate a contingency branch
4. Integrate & evaluate the branch

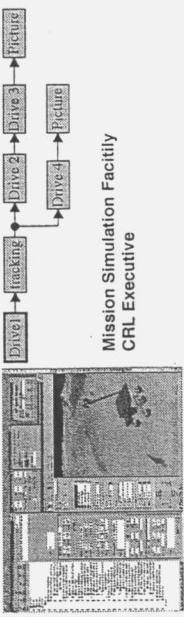
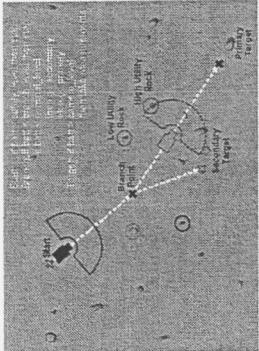


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- Generate sequence
  - Concurrent Contingent Rover Language (C-CRL)
- Execute sequence in simulation
- Iterate planning process until satisfied
- Uplink to rover

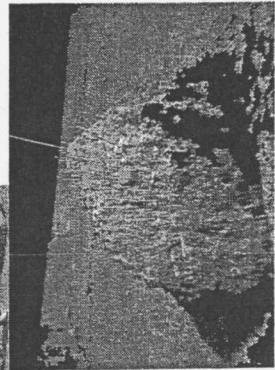
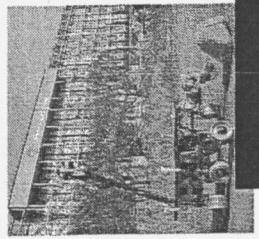


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## Sequence Execution

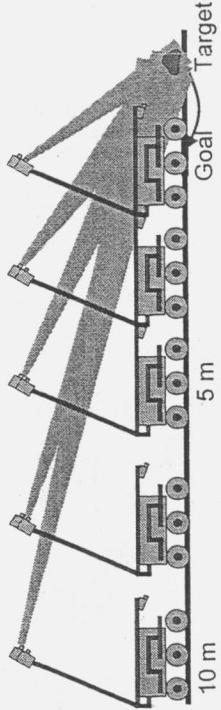
- Track targets and navigate to them
- At each target in sequence do:
  - Safety check
  - Safe placement on target
  - Acquire science data
- Monitor resources (time, energy) and tracking status
- Do alternate plans if off nominal
- Uplink science data back to Mission Control



## Visual Target Tracking

Multiple targets, 10m distant targets, 1cm precision

- Long (> 20m) traverses
  - Large deduced reckoning error (~10% distance traveled)
  - 2-3 hrs tracking duration
- Large target appearance changes

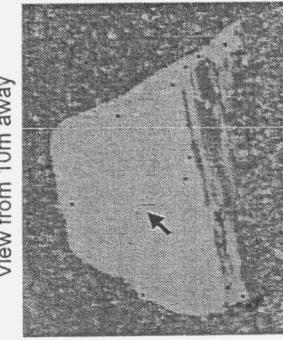


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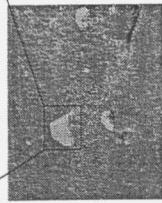
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## Featureless Targets, Scale Changes & Shadows

View from 1m away



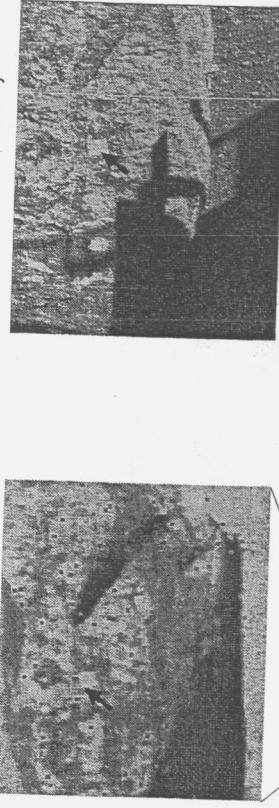
- Target point selected by scientists may not correspond to any visually distinctive features
- Note appearance of texture and rover shadow in close up image
- Note: 10m traverse → 10:1 scale change



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## NASA JPL Research Center Lighting Changes

View from 10m away

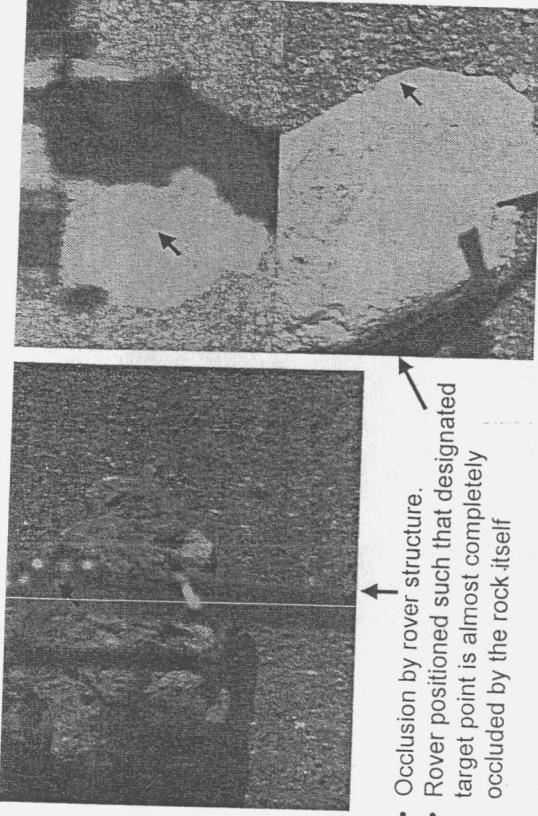


- 10:1 scale change (texture changes)
- Lighting changes
  - Rover shadow
  - Change in position of sun over course of 1-3 hrs sequence execution.

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## NASA JPL Research Center Occlusions & Orientation Changes

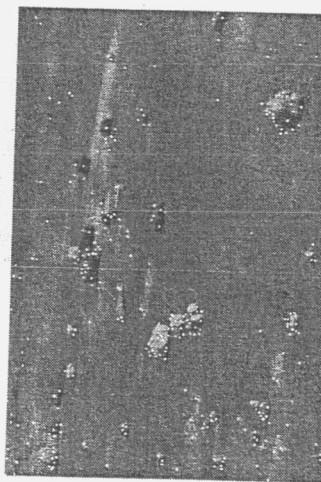


- Occlusion by rover structure.
- Rover positioned such that designated target point is almost completely occluded by the rock itself

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## NASA JPL Research Center Approach: 2D Interest Points



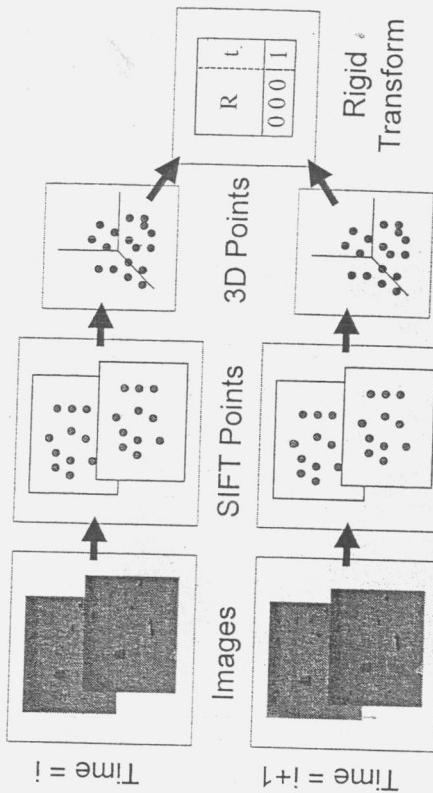
SIFT interest operator/descriptor  
Fast global matching, no "search"

[Lowe, D. G., "Distinctive image features from scale-invariant keypoints,"  
*International Journal of Computer Vision*, submitted June 2003.]

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## NASA JPL Research Center 3D SIFT Target Tracker



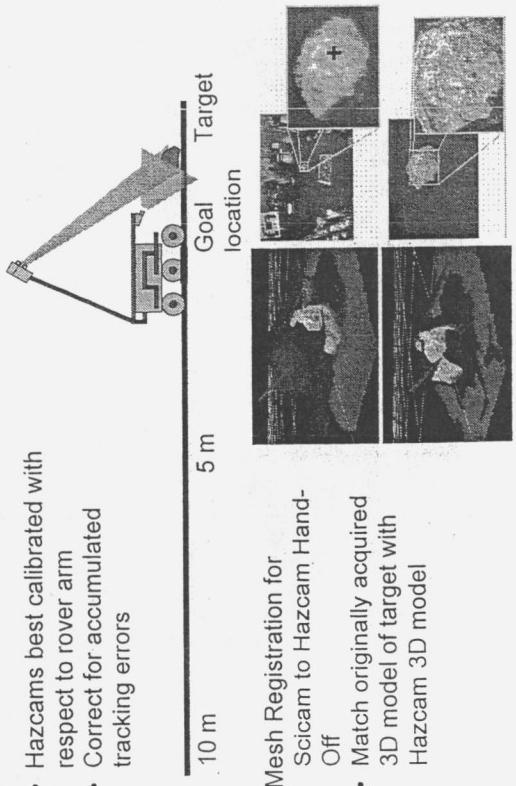
- Integrate motion estimates for each target throughout traverse
- Small increasing tracking error during traverse

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## Camera Hand-off

- Hazcams best calibrated with respect to rover arm
- Correct for accumulated tracking errors

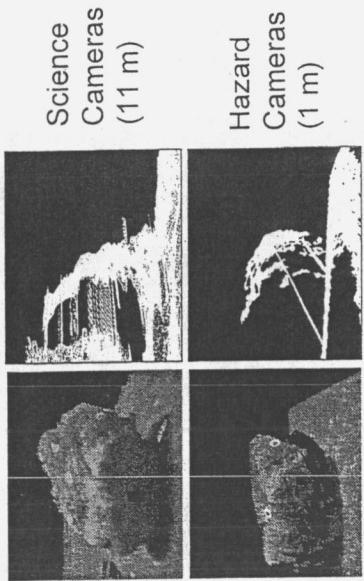


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## Safe Placement

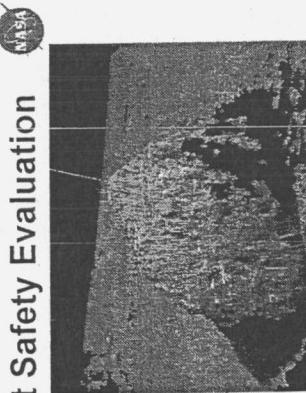


- Cannot guarantee target point chosen from 10m won't damage instrument.
- Potentially large tracking/hand-off error
- Close evaluation of target to confirm presumed target point is safe, and find close alternate if not.

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## Instrument Placement Safety Evaluation



- Safety Check
  - Confirm target area will not damage instrument
  - Find nearest safe locations
- Motion Planning
  - Confirm reachable and collision free path
  - Placement
  - Confirm with contact sensors
- Take measurement

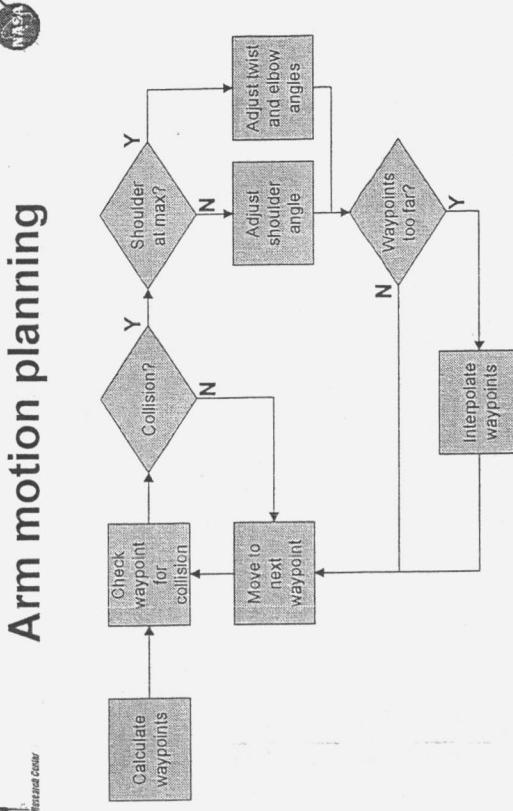


Uses several geometric criteria to ensure safety of instrument Placement location

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## Arm motion planning



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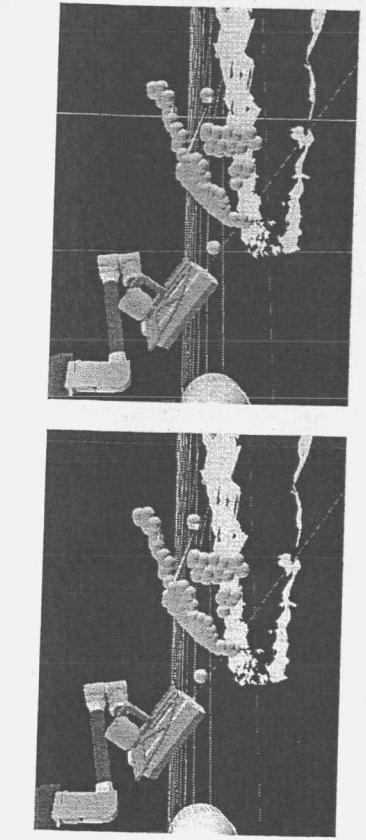
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## Arm motion planning



NASA  
Ames Research Center

## Data Products & Execution Review



Original waypoints

Safe arm motion

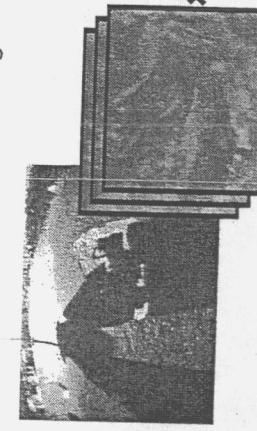
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## Round Trip Data Tracking



Hazcam  
CHAMP



Colib Panorama 10/22/04 (S) 21 Oct 2004 04:32 - Observations List	
Order	Target position
1	Target 1
2	Target 2
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11	Target 11
12	Target 12
13	Target 13
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    - Research Groups
      - Intelligent Robotics
      - Planning and Scheduling
      - Collaborative Assistant Systems
      - Manipulation Task (JPL)
    - Project Management
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  - Greg Pisanich
  - Lorenzo Flueckiger
  - Laura Plice
  - Michael Wagner
  - Chris Neukom
  - Eric Buchanan
  - Contingent Planning
    - David E. Smith
    - Nicolas Meauleau
    - David Roland
    - Sainlesh Ramakrishnan
    - Matthew Boyce
    - Ted Morse
    - Mars Science
      - Nathalie Cabrol
      - Gloria Hovde
  - CRL Executive
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- Mission-Simulation Facility
  - Greg Pisanich
  - Lorenzo Flueckiger
  - Laura Plice
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